VOLKMANN'S ISCHEMIC PARALYSIS.*

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ISCHEMIC paralysis, first described by Volkmann in 1880–81, is a comparatively rare lesion if one is to judge by the small number of cases in the literature. However, as its importance has been emphasized in the last few years, a rapidly increasing number of cases has been reported. In 1904, Schramm could collect only 27 cases. In 1907, Powers collected 52 cases, to which I am able to add 6 cases from the recent literature and one personal case which will be described later. In the last four years more cases have been reported than in the preceding twenty-four years, which is rather an index of the increasing interest in the subject, than of the greater frequency of the lesion.

In all but two of the 59 cases the forearm was involved (flexor muscles). The other two cases occurred in the flexors of the leg and foot. The great majority of cases occur in children from three to twelve years old. Their vessels are less mature and the circulation of their muscles is more easily disturbed. The underlying cause in all these cases is ischemia (or, better, oxygen-deprivation), which may be induced by direct compression of the vessels and muscles, or by contusion, laceration, thrombosis, or embolism of the vessels. These factors may be more or less combined. At least 80 per cent. of the cases reported have followed fractures where splints or plaster bandages have been too firmly applied. The fractures have involved the arm and forearm in about equal numbers; always the lower third of the humerus in the arm, and usually the middle of the bones in the forearm. Complete ischemia,

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persisting for more than six hours, is almost sure to be followed by serious contracture.

Pathological Changes.—At the time of injury, the circulation distal to the fracture is interfered with by the mechanical displacement of the fragments, and the effusion of blood which is greater than is usually supposed (Hildebrand). The artery may be narrowed, torn across, or thrombotic. At a later time the artery may be entirely obliterated for a considerable distance, as in Peterson's case. Too tightly applied dressings not only enhance the obstruction to the arterial supply but add the element of direct pressure upon the muscle-substance itself. How important a factor this direct pressure may be, is indicated by the formation of areas of pressure-necrosis and abscess in the proximal portion of the flexor muscles and skin of the forearm, where the pressure is greatest, in 60 per cent. of Schramm's cases. Riedinger believes the direct mechanical pressure upon the muscles is the important factor more often than interference with the arterial supply, since, in his four cases the area of muscle damage was exactly coincident with the pressure-area. In either case, if the pressure continues for more than six hours, the muscle substance rapidly degenerates, enters a condition of rigor mortis, and shortens, causing the typical deformity. When the pressure is relieved, there is marked effusion from the damaged vessels, and round-celled infiltration of the soft tissues. The muscle is more or less replaced by connective tissue according to the severity of the case. With the lapse of time the cicatrix becomes harder, shorter and the deformity more fixed.

Primarily the nerves may show no change, or may show degeneration as a result of the ischemia and pressure. Later, whether primarily involved or not, they may suffer degeneration from the pressure of the contracting cicatrized muscles, and this in turn results in atrophic changes in their muscle-fields. In the area of compression the nerves are often nothing but fibrous bands, while above, they are thicker and softer than normal from congestion. Sometimes they are nodular from irregular compression.

The symptoms, in rapidity of onset and severity, depend upon the degree of ischemia present and its duration. In the severe cases, the symptoms are prompt in appearance and very characteristic. Almost immediately after the application of the tight dressings the patient makes vigorous complaint of pain. If the splint is not promptly removed, the pain increases in severity, marked swelling occurs in the hand and fingers, together with purple discoloration and the formation of skin-blebs. Within twenty-four hours the hand assumes the claw-shape resulting from contracture of the damaged flexor muscles, and if the dressing be not then removed, necrosis of the skin and flexor muscles is very apt to occur a short distance below the elbow (60 per cent. of Schramm's cases).

On removal of the splint, the flexor muscles are very hard and board-like to the touch, and the extremity is in characteristic position. The elbow is slightly flexed, the forearm pronated, the wrist slightly flexed, and the fingers strongly flexed in the claw-hand position. When the wrist is extended as much as possible, the fingers cannot be extended by any degree of force short of that sufficient to break the bones or rupture the tendons. When the wrist is fully flexed, the fingers may readily be extended by passive motion, although in bad cases this extension may not be complete. When the wrist is extended the fingers automatically flex and cannot be prevented from doing so by any degree of resistance. All attempts at extension, in whatever position, cause the cicatrized muscles to spring into prominence between the internal epicondyle and the front of the wrist. In the severest cases the contracture is sufficient to drive the fingernails into the palm of the hand.

When the nerves (usually median and ulnar) are primarily damaged by the ischemia, there is loss of sensation and paralysis of the muscle-field, which is partial or complete, according to the degree of nerve injury. When the nerves are not primarily involved they are very apt to undergo degeneration from compression by the cicatrization of the muscles. In either case, when nerve damage is present, there will develop trophic changes (blue, cold, glossy, thin skin), and mus-

cular atrophy in the nerve-field, in addition to loss of sensation and paralysis.

In less severe cases the symptoms develop more slowly.

Diagnosis.—When, after the application of firm dressings to a fractured extremity, there appear rapidly and simultaneously, pain, swelling, discoloration, flexion-contracture of the fingers and wrist, with loss of power to extend them either actively or passively, ischemic paralysis is present. Paralysis due to nerve injury is very different. Here the muscles are flaccid, permit passive motion through the full range, and contracture when it does occur is late in appearing and slow in development. The characteristic features then, of ischemic paralysis, are the rapid and simultaneous onset of loss of function, flexor-contracture, and rigid resistance to passive extension.

It is important, both for purposes of prognosis and treatment, to determine whether the nerves have been involved either early or late in the process. If the muscle responds, even though very faintly, to both faradic and galvanic current, there is no nerve injury. If the muscle responds to galvanic but not to faradic current, there is nerve injury. If the muscle responds to neither galvanic nor faradic current, there is complete muscle injury; nerve injury not determined. In this last contingency help may be derived from the examination of the muscles of the hand (interossei, lumbricales, thenar and hypothenar groups) which are very seldom or never involved in the ischemic lesion. According to the reactions of these muscles, it can be determined whether or not nerve impulses pass through the damaged area above, and therefore whether the nerves themselves are damaged.

Prognosis.—The prognosis varies not only with the degree of muscle and nerve damage, but depends decidedly upon the promptness and energy of treatment. In general the prognosis is unfavorable. Where the muscle has been entirely cicatrized there is no hope whatever. When only a small portion of muscle has been involved, proper treatment may

result in complete or nearly complete cure. Between these two extremes there are many degrees of recovery.

Treatment.—Bearing upon the subject of treatment are certain important facts derived from experimental research. Lapinsky caused ischemia in dogs' legs by tying the chief arteries. If the collateral circulation was allowed to develop, power slowly returned in the paralyzed muscles without inflammatory reaction. When, however, blood was allowed to return rapidly into the vessels weakened by prolonged absence of oxygen, effusion, swelling, and interference with the return of power in the muscles occurred. Leser caused ischemia in dogs' legs by tight splints. When the ischemic contracture had developed, if the splint was removed and the dog allowed to run free, the muscles soon returned to normal condition. If the limb was immediately re-immobilized, whether with a tight or loose dressing, a permanent contracture developed. This means that activity of the muscle substance so improves its circulation and nutrition as to prevent the degenerative changes which follow continued immobilization.

Treatment, based upon the sequence of pathological changes and the results of experimental work, must be early and vigorous. The longer ischemic paralysis has existed, the more difficult it is to cure; in fact, other things being equal, the success of treatment varies almost inversely as the time elapsed since injury. The cicatrization of the muscles, which is the essential feature of the condition, becomes more complete the longer the contracture exists. Prophylaxis is most important. No tight primary dressing nor any form of treatment which would cause circulatory obstruction should be applied to any fracture, especially in children when it involves the region of the elbow-joint, for this combination of circumstances is present in 96 per cent. of the reported cases. In every form of dressing allowance must be made for post-traumatic swelling. Frequent inspection or report, at intervals of not more than four hours, should be insisted upon for the first twenty-four hours. The dressing should be promptly removed if the patient complains of increasing pain, or if

swelling or discoloration appear with or without beginning flexor-contracture.

In every case reported in the literature, the removal of the primary dressing has been followed by the application of another, which, while looser, has continued the immobilization of the muscles. In the light of Leser's experiments this is faulty treatment. Not only should the primary dressing be removed but massage, electricity, active motion if possible, vigorous passive motion, under an anesthetic if necessary, should be used to restore the circulation in the damaged muscles. During these procedures proper support should be given to the fracture by an assistant, and afterwards the extremity should be lightly bandaged to prevent too much effusion into the damaged muscles. These measures should be repeated every few hours until the muscles are in good condition again, when attention may once more be directed to the fracture itself. Even if this treatment should result in malunion, non-union, or pseudarthrosis, either of these conditions is much less troublesome and more easily corrected than an ischemic contracture.

After the condition is once present, there is a choice between non-operative and operative treatment. Non-operative treatment consists in baths, massage, electricity, and passive motion. Some authors advise repeated strenuous extensions of the wrist and fingers, under an anesthetic if necessary.

Martin (C.) reported a case in which continuous slow elastic traction gave a most satisfactory result in a comparatively short time.

Sayre (R.) recently showed a case (see bibliography) where a very good result was obtained after using mechanical extension for six months. In both these cases the contracture did not appear for some six or seven weeks after the injury and it would seem probable that not so much of the muscle substance was damaged as in the cases with more rapid onset. Therefore a favorable result might be expected.

In severe cases, where the circulation is more seriously

damaged, these mechanical appliances involve a degree of risk, for pressure sores occur upon slight provocation.

Non-operative treatment is tedious, difficult, and the majority of results reported are not satisfactory. It gives no relief to compressed nerves.

Operative treatment gives quicker and more complete results according to the statistics of the published cases. In many of the operative cases palliative treatment had been tried for long periods of time without result.

There are two operative procedures each of which has its advocates: Tendon-lengthening, in which the flexor tendons are elongated sufficiently to permit complete simultaneous extension of the wrist and fingers. Advantages—no shortening of the forearm; no chance of mal-union, non-union, or pseudarthrosis. Disadvantages—operation is tedious; tendons may become mixed, adherent to each other and to the skin cicatrix, thus limiting mobility; the nerves may be injured or divided and sutured by mistake to tendon, as has happened in some of the reported cases.

To minimize adhesions to the skin some operators make a U-shaped flap with the convexity upward.

Resection of both bones of the forearm was first advised by Henle in 1896. Enough (1.5 to 2 cm.) is removed to permit complete extension of the wrist and fingers simultaneously. (See appended case-history.) Advantages—operation is short; avoids adhesions of tendons to each other and to skin; avoids damage to nerves. Disadvantages—forearm is shortened; there is possibility of mal-union, non-union, or pseudarthrosis. (Non-union has been reported once.)

Both operations have given good results and both ultimately act in the same way by eliminating the deformity, increasing the range of passive motion, relieving the extensor muscles from overstretching, and placing the flexor muscles under conditions most favorable to regeneration. The ultimate result depends on the amount of muscle regeneration in the cicatricial area. The greatest stimulus to regeneration comes from voluntary contraction of such muscle as is left.

Both operations, by relieving the tension, not only favor such voluntary contraction, but greatly increase the circulation and nutrition of the muscle.

While tendoplasty has its warm advocates, most operators are turning to resection of both bones of the forearm because it reaches the same result by a shorter, simpler method. The danger of non-union is small, and the slight shortening causes no functional disturbance.

In every case presenting signs of nerve compression, whether primarily or secondarily, the nerves (median and ulnar) should be released. Freeman, who especially emphasizes the frequency and importance of nerve lesions in these cases, advocates transferring the nerves to a subcutaneous position, or excising some of the cicatrized muscle to allow more space for the nerve in its natural position.

When the flexor muscles have been completely changed to fibrous tissue, of course no procedure can cause regeneration. Since, however, it cannot be determined clinically when the muscle is entirely gone, no case should be denied the benefit of the doubt and refused the operation.

Even in cases which give no hope of the return of motor power, much can be done to relieve trophic and sensory disturbances by neurolysis.

In the report of the two cases involving the foot and leg, subcutaneous tenotomy of the flexor tendons relieved the talipes equinus and gave a useful leg, although flexor power was entirely absent.

In two cases in the forearm, tenotomy of the flexors was done at the wrist, with the result of making a better looking but perfectly useless extremity.

As soon as the tendons or bones, according to the operation done, have firmly united, baths, massage, electricity, and passive motion should be employed vigorously and systematically until function has been restored to the muscles. Active use of the extremity should be encouraged at the earliest moment.

The object of after-treatment is to cause absorption of

cicatricial tissue and regeneration of muscle tissue. In the case reported below, progress seemed to be materially aided by preceding the bath and massage by congestive hyperemia for one to two hours, and combining the inunction of mercurial ointment into the cicatricial area with the massage.

Hope must not be given up even if no apparent progress is made for months, as these cases are invariably tedious, especially when the nerves have been involved.

CASE HISTORY.—Louis K. fell and broke the lower end of the right humerus on May 5, 1906. He was 4 years, 9 months old. One hour after the injury a plaster splint was applied. The next day the extremity was very painful and the hand was swollen, cyanotic, and covered with large blebs. The pains gradually subsided. On the seventh day, when the splint was first removed, there was an abscess involving the skin and flexor muscles just below the elbow, and a well marked, rigid, flexor-contracture of the wrist and fingers. The abscess was treated and the splint replaced. After four weeks the splint was discarded and the abscess was still discharging.

For eight months massage, electricity, passive motion, and vibration were tried with absolutely no benefit. Then, January, 1907, thinking the trouble was due to inclusion of the musculospiral nerve in the callus, an incision was made over the nerve at the outer side of the elbow. The nerve was not involved. The previous treatment was continued until June, 1907 (13 months), when he was referred to me by Dr. S. A. Twinch, who was not, however, responsible for the treatment of the original fracture.

Physical Examination.—A boy, slender, blonde, and in good general condition. The right arm is freely movable in all directions at the shoulder. There is moderate convex deformity above the external condyle of the humerus, result of the old fracture, resembling gunstock deformity. There is a linear scar over the outer aspect of the elbow from the incision over the musculospiral nerve. Just below the elbow on the flexor surface is the scar of the old abscess, 4 x 2 cm. The hand is cold, blue, with thin, shiny skin, and with trophic disturbances of the finger-tips, as indicated by thickened, corrugated nails, and red, shiny skin,

showing a tendency to ulcerate, especially on the tips of the index and middle fingers. The forearm, wrist, and hand are rigid, with the wrist flexed about 20°, the metacarpo-phalangeal joints slightly extended and the remaining finger joints about half flexed. It closely resembles "main-en-griffe." An unyielding, rigid band runs along the flexor aspect of the forearm from the internal condyle of the humerus to the wrist, which becomes more prominent on attempting to extend the wrist and fingers, and evidently prevents such extension. This same band prevents full extension of the elbow. All the flexors of the fingers are apparently involved in this cicatricial mass.

Active Motion.—Absent in the wrist joint. Very slight power of extension at the metacarpo-phalangeal joints. The extensor muscles contract definitely but cannot overcome the flexor contracture. The musculo-spiral nerve is therefore undamaged. The fingers spring back to their positions instead of being drawn back by flexor contraction. The fingers cannot be flexed.

Passive Motion.—The wrist can be fully flexed and, when held in this position, the fingers can be fully extended on the hand. When the wrist is brought back to the limit of its extension, the fingers, pari passu, resume their flexed position and no amount of force can prevent them from doing so. When the wrist is held at its limit of extension, the fingers can be fully flexed but can be extended only very slightly beyond the position they naturally assume when left alone.

There is atrophy of the interossei, thenar, and hypothenar muscles, and this, together with the trophic changes in the fingers, indicates that both the ulnar and median nerves are damaged.

Operation July 6, 1907. Ether. A 10 cm. longitudinal incision was made over the middle of the forearm just below the elbow. The flexors, superficial and deep, seemed to be entirely fibrous. An incision was made through them to expose the median nerve. They were mostly fibrous tissue with a few muscle fibres scattered here and there. There was but little bleeding. The median nerve, beginning where it passes between the two heads of the pronator radii teres, was compressed, thin, and white for a distance of 5 cm. downward. Above this area the nerve was much thicker and more congested than normal, while below, it was about normal in size and appearance. The

nerve was freed and wrapped in Cargile membrane. The ulnar nerve was compressed but not so much as the median. It was treated in the same way. The muscles were lightly sutured with catgut and the skin closed with silk.

By the subperiosteal method, 2 cm. of each bone of the forearm was removed; in the ulna 5 cm., and in the radius 7 cm. above its lower end. Different levels were chosen to avoid possible difficulty from cross union, and also to make it easier to hold the bones in position. The bones bled freely.

With the bones thus shortened the wrist and fingers could be extended simultaneously and fully. The marrow canals of the bones were too small to permit the use of Elsberg aluminum tubes inside, so tubes just large enough to receive the bone-ends were fitted in subperiosteally, the bones slipped into them and the periosteum sutured over them with catgut. The skin was closed with silk without drainage. The extremity was put up on an anterior splint with the fingers and wrist fully extended. All the wounds healed by primary union.

Post-operative History.—August 24, seven weeks after operation, the bones are firmly united. There is a fusiform swelling over the aluminum tube on each bone. Splint was discarded. The wrist and fingers can be fully and simultaneously extended by passive motion.

October 30 (3 months, 24 days). There is some return of the flexion contracture of the wrist and fingers. Marked improvement in the warmth, color, and nutrition of the hand. The thumb can be adducted and slightly flexed voluntarily. The fingers can be slightly moved by the extensors, but flexed only by the interossei so that the distal joints extend while the metacarpophalangeal joints flex. Fusiform swellings still persist at the points of resection.

February 3, 1908 (7 months). The contracture at the wrist and fingers has slightly increased. The interossei and thenar muscles are distinctly less atrophied and the thumb can be slightly flexed and well adducted so as to firmly grasp things between it and the side of the index finger. The little finger can be slightly flexed. The index, ring and middle fingers can be flexed only at the metacarpo-phalangeal joints, by the interossei muscles. All the digits can be slightly extended voluntarily. The elbow can

FIG. 1.

X-ray picture taken nine months after operation for ischemic paralysis. 1. Site of resection of the radius, showing the aluminum tube still in the callus. 2. Site of resection of the ulna, showing the tube more distinctly and a larger callus. The perfect alignment of both bones obtained by using tubes is clearly shown.

be extended a little more than before operation. The cicatricial mass seems to have diminished a little in size and rigidity. The fusiform swelling over the radius has entirely disappeared; over the ulna, the swelling is much larger as the result of a fall a few days ago. (Fig. 1.)

March 6, 1908 (8 months). The swelling on the ulna is much diminished. The hand is normal in color, temperature, and trophic appearance of the skin, and the interossei, thenar and hypothenar muscles are evidently returning to their normal size. Voluntary extension of the fingers is stronger. There is slight flexion of the fingers apparently by the long flexors.

In this case the history was characteristic and the onset was sudden, as indicated by the appearance, within twenty-four hours, of swelling, cyanosis, and skin-blebs of the hand. Abscess of the flexor muscles indicated a severe case. Non-operative treatment was carried out vigorously and systematically for thirteen months with absolutely no benefit. Operative treatment was then tried as offering the only hope left, although this was small. After eight months, there is slight improvement in mobility of the wrist and fingers, the appearance of very slight power to flex the tips of the fingers, marked improvement in power and movement of the thumb, development of the interossei and thenar muscles, and the return of normal trophic conditions to the hand and fingers.

The greatest improvement has occurred in the last two months, so that there is much to hope from the future of the case.

Summary.—Ischemic paralysis is essentially a myositis resulting from prolonged absence from the muscle of oxygenated blood. Muscle substance is replaced by fibrous tissue in proportion to the severity of the case, with a corresponding degree and rigidity of contracture.

The nerves are frequently involved, either primarily from the ischemia and pressure, or secondarily from compression by the cicatricial mass. This form of paralysis occurs, nearly always, in the forearm after too tight dressings have been

applied to fractures near the elbow. The great majority of cases occur in children from three to twelve years old.

Diagnostic Symptoms.—Early onset of severe pain and swelling; simultaneous appearance of rigid contracture with the paralysis of the muscles, causing the characteristic "claw-hand." The simultaneous appearance of the contracture with the paralysis differentiates these cases from palsies due purely to nerve lesions.

Severe cases may result from six hours of tight compression.

Evidence of damage to nerves should always be sought.

Treatment.—Prophylaxis is most important. No tight dressings should be used on any fractures, especially when they are near the elbow-joint in children. In all dressings allowance must be made for traumatic reactionary swelling. Frequent inspections of dressings must be made for the first two days after injury.

When the lesion occurs, dressings must be removed, the fracture neglected for the time being, and attention paid solely to the return of muscle nutrition and function.

Non-operative treatment consists in the use of massage, electricity, vigorous passive motion, etc. (so-called physical therapeutics).

Operative Treatment.—Lengthening of the tendons of the shortened muscles sufficiently to permit simultaneous extension of the wrist and fingers.

Resection of both bones of the forearm is a simpler and probably a better operation. Enough is removed to permit full extension of the wrist and fingers.

Either operation relieves the excessive tension and favors muscle regeneration.

In all cases damaged nerves should be properly cared for.

After-treatment consists of physical therapeutics and must be vigorously and systematically applied.

Prognosis is on the whole unfavorable; complete cure is rare; improvement often comes only after months or years of steady work.

Results are better the earlier and more vigorous the treatment.*

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* It was brought out in the discussion by Dr. Erdmann at the New York Surgical Society that the gradually returning contracture of the wrist and fingers was due rather to the growth of the bones of the forearm than to further contracture of the cicatricial mass of muscles.

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Case 1.—Girl, 10 years old; fracture of both bones of forearm; almost perfect result.

Case 2.—Boy, 19 years old; injury of fleshy part of forearm without fracture; improvement.

Case 3.—Boy, 16 years old; fracture of olecranon; observed only for one month, but there was improvement in sensation.

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